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Modern Techniques to characterize Phase and Group Delay of Frequency Converters

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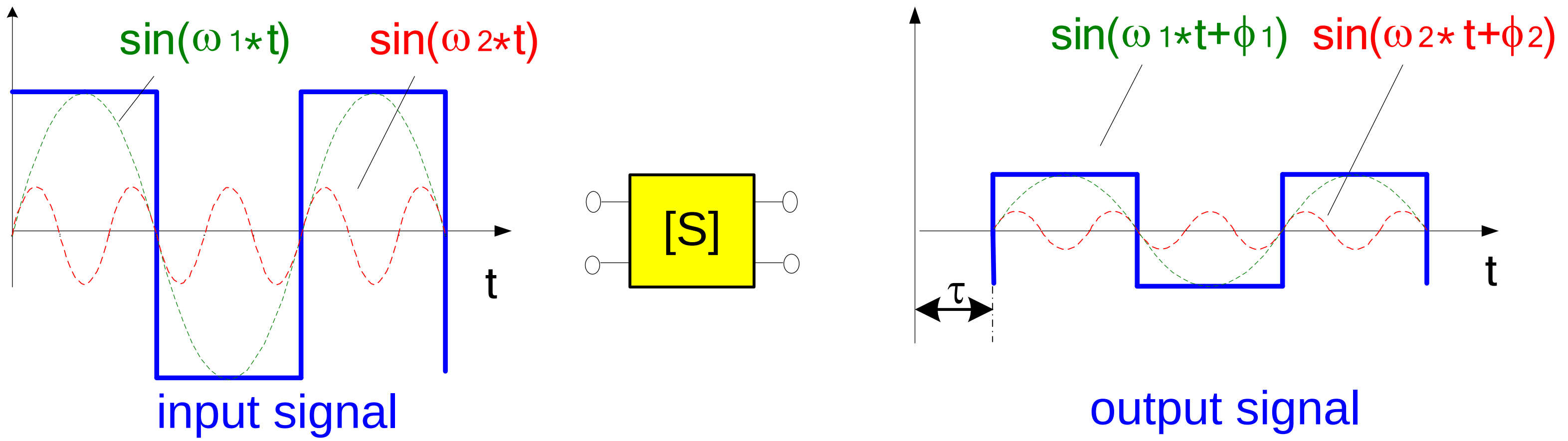
Overview

- Group delay – the key parameter for good data transmission
- Group delay measurements on frequency converters drawbacks of traditional approaches
- Group delay measurements with new two-tone technique
- Measurement of a typical frequency converters
- Group delay test on a satellite in orbit

What is required for good Data Transmission



- Constant attenuation for all spectral components within the transmission channel
  - Characterized by conversion loss or magnitude of S21

- Identical time shift for all spectral components

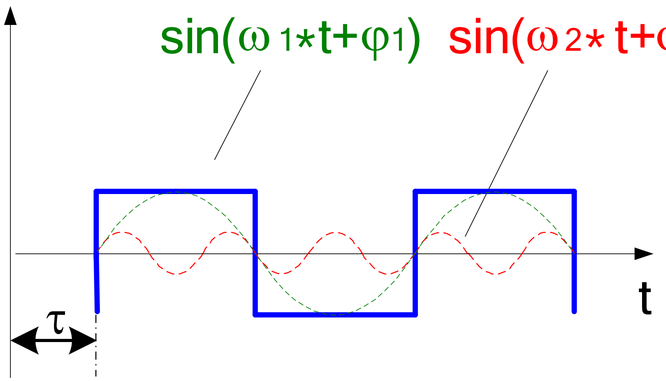
What does constant Time Shift mean for the Phase

$$\varphi = -\omega \cdot \tau$$

$$\varphi_1 = -\omega_1 \cdot \tau$$

$$\varphi_2 = -\omega_2 \cdot \tau$$

$$\varphi_2 - \varphi_1 = -\tau \cdot \left(\omega_2 - \omega_1\right)$$



$$\boxed{-\frac{\Delta\varphi}{\Delta\omega} = \tau}$$

with $\Delta\varphi = \varphi_2 - \varphi_1$ *and* $\Delta\omega = \omega_2 - \omega_1$

What does constant Time Shift mean

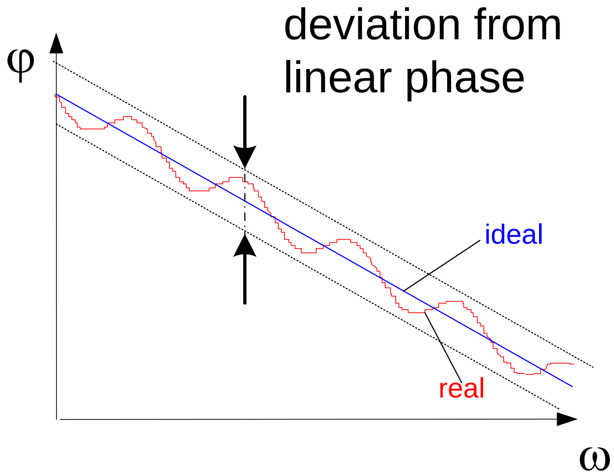
- Phase of transmission parameter (S21 or conversion loss) must in- or decrease linearly with increasing frequencies

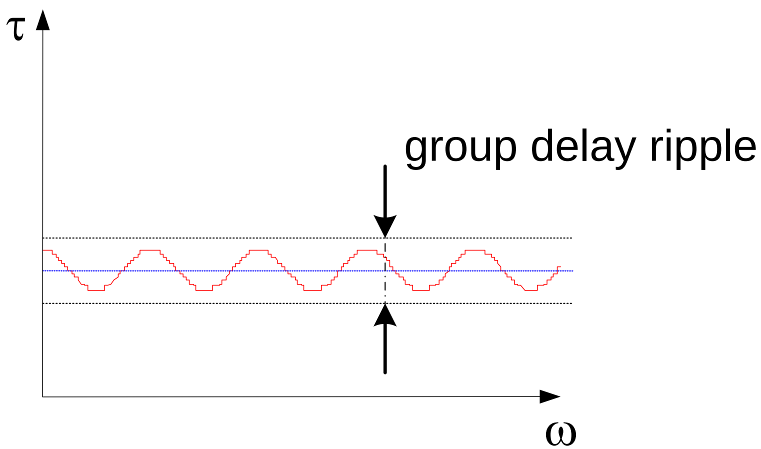
- Time shift or average signal transit time is the so-called group delay and is calculated as

$$\tau = -\frac{1}{360^\circ} \bullet \frac{d\varphi}{df}$$

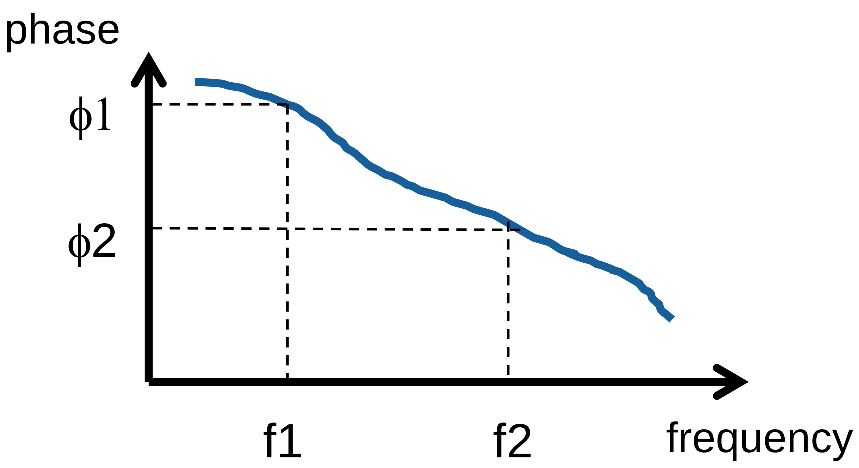
Group Delay and Deviation from linear Phase

- Deviation from constant group delay („group delay ripple“) causes signal distortion
- Deviation from linear phase is also used as a measure of transmission quality





Definition of the Group Delay



$$\tau = -\frac{1}{360°} \bullet \frac{\Delta phase}{\Delta frequency}$$

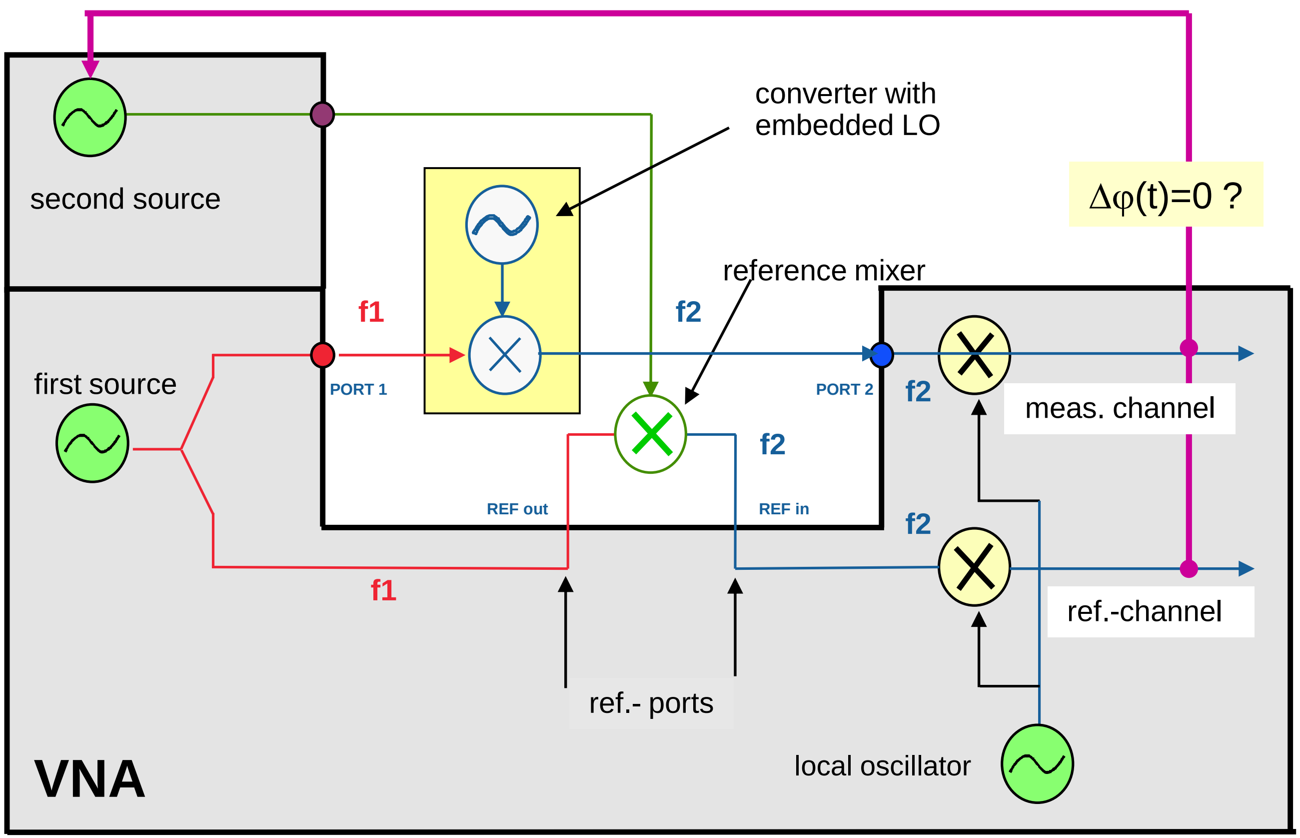
- For non frequency converting DUT, the Group Delay can be calculated out of two S21 measurements
- For frequency converting DUT, it‘s a difficult because the input and output signals are at different frequencies

Group Delay Measurement without LO Access until now …

- Based on a reference mixer technique
- Tracking the phase of the IF of the DUT to adjust the external LO used for the reference channel mixer to the embedded LO

  => Reconstruction of the LO

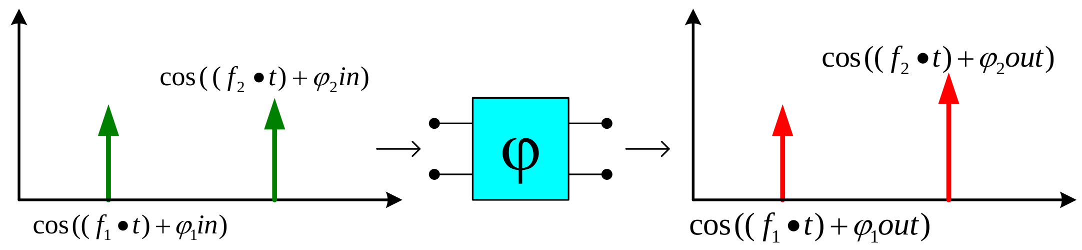
Old Approach Reconstructing the Embedded LO



Group Delay Measurement on Converters with Reconstruction of the LO

- DUT‘s LO has to have a high frequency stability
  - LO is no longer monitored once a measurement is started
  - Problems with measurements that require long measurement time
- Multistage-converters cannot be addressed using this technique as the phase to frequency offset relation is no longer linear

New Solution - Two Tone Method of ZNA



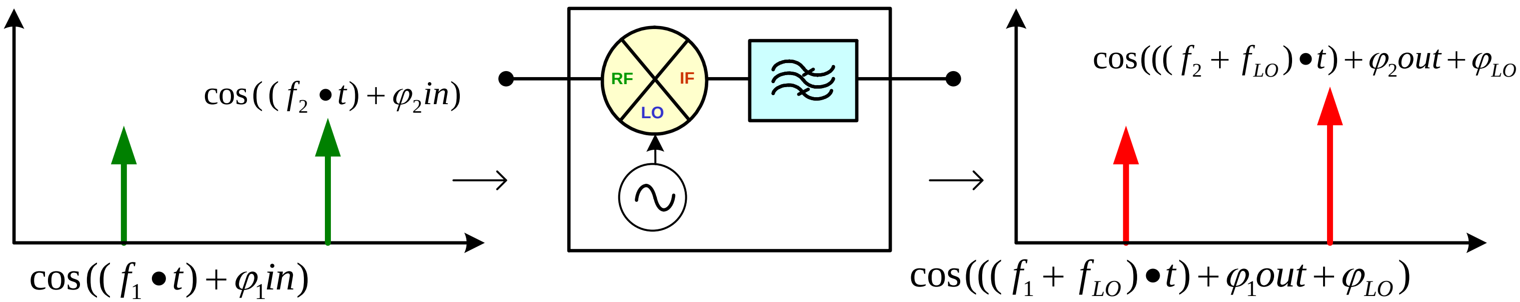
- Two signals at frequencies f1 and f2 injected into the DUT
- Phase shifts at the output due to the phase response of the DUT
- VNA measures phase differences at the input and the output

$\Delta f = f1 - f2$

$$\Delta\varphi = (\varphi 1out - \varphi 2out) - (\varphi 1in - \varphi 2in)$$

$$\tau = \frac{-1}{360^\circ} \bullet \frac{\Delta\varphi}{\Delta f}$$

The Measurement of a Converter with ZNA



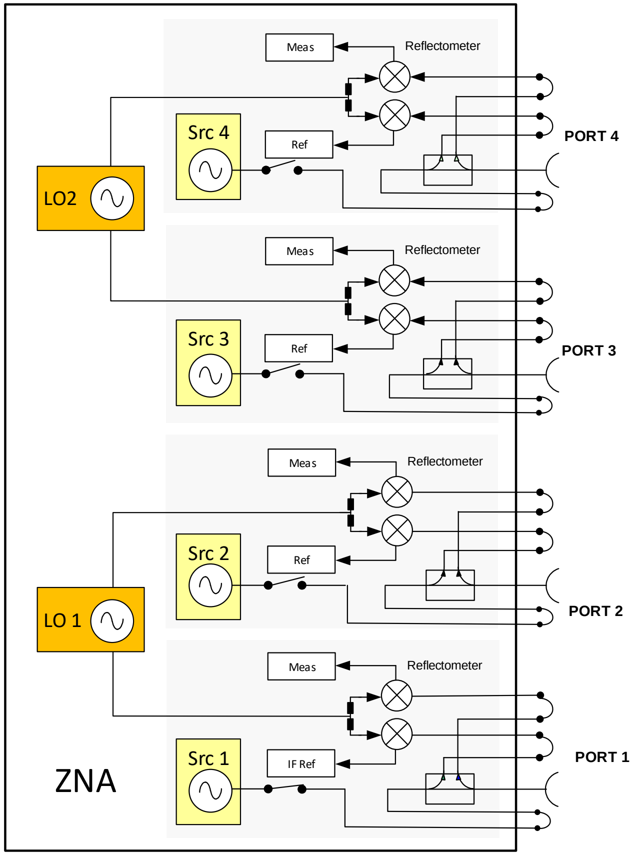
- An LO phase is added to φ1out and φ2out by same amount
- The difference of φ1out and φ2out is independent of the LO phase
  - LO phase and frequency shifts are cancelled out

$$\Delta\varphi = (\varphi 1out + \varphi LO - \varphi 2out - \varphi LO) - (\varphi 1in - \varphi 2in)$$

$$\tau = \frac{-1}{360^\circ} \bullet \frac{\Delta\varphi}{\Delta f}$$

The ZNA Architecture for Group Delay Measurements

- 4 ports
- 4 sources, one per port
- 2 internal LOs
  - Port 1 / 2 and port 3 / 4
- 8 analog receivers
- 8 digital receivers

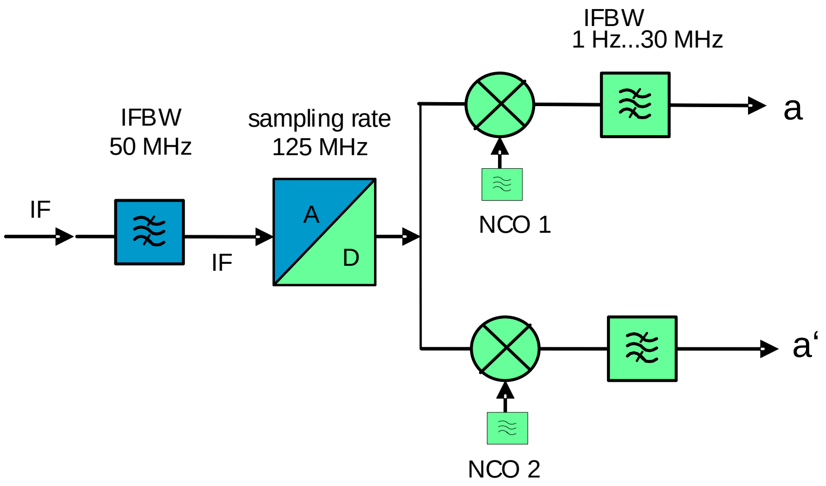


Digital Dual Receiver Frontend of ZNA

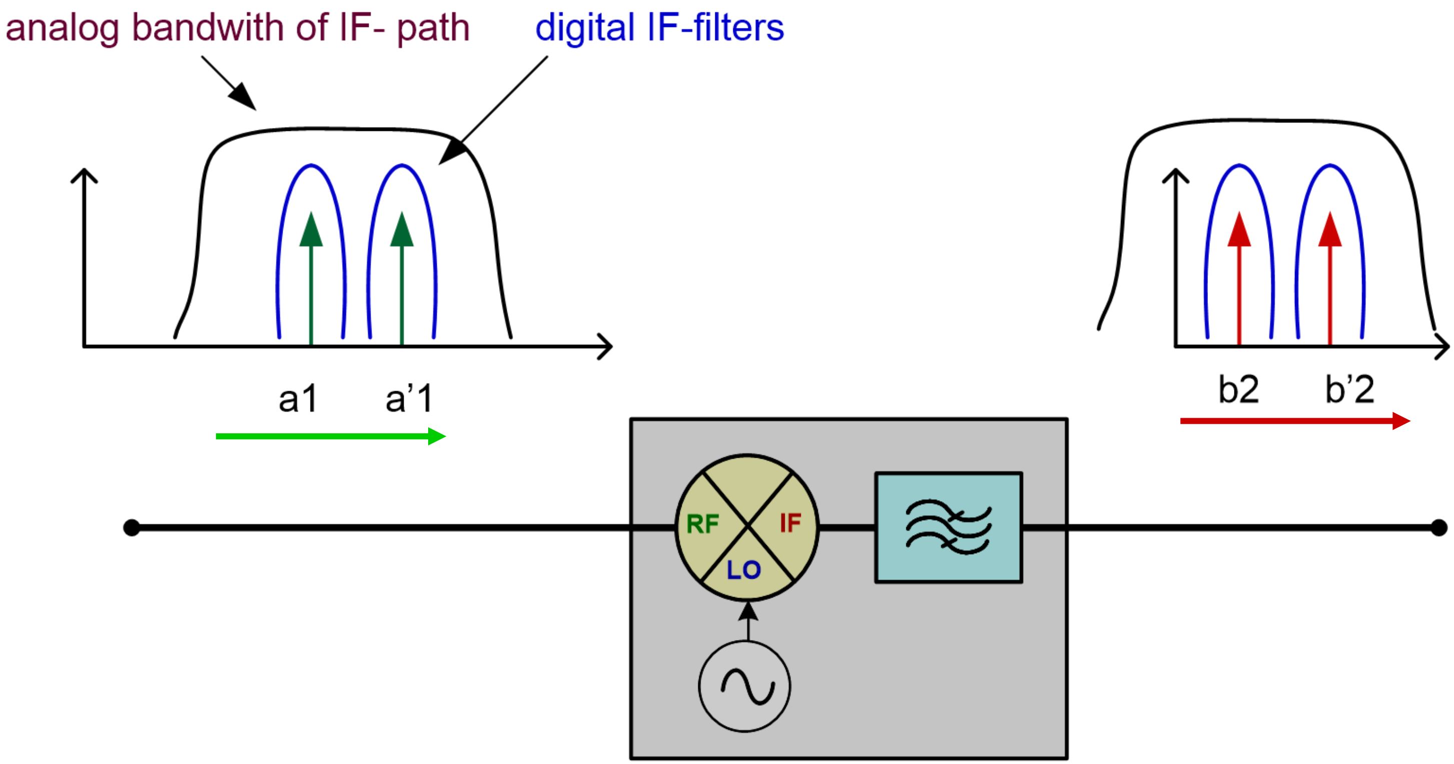
- RF signal is down-converted to IF of about 30 MHz
- A/D conversion with 125 MHz

- Two digital down converter with independent NCOs (numerical controlled oscillators)

- NCO1 and NCO2 get the frequency offset of the 2-tone signals
- Both tones are digital down-converted to IF=0 => a1 ; a‘1
- Enables measurement of the phase of both signals



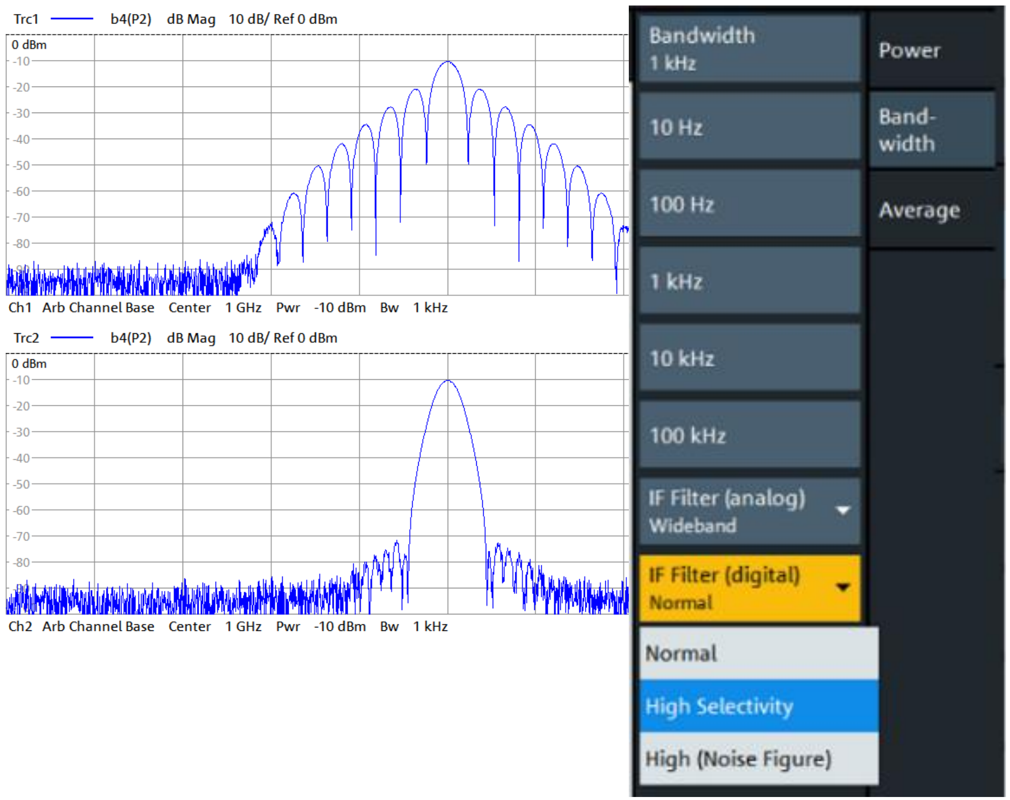
Using “dashed” Wave Quantities



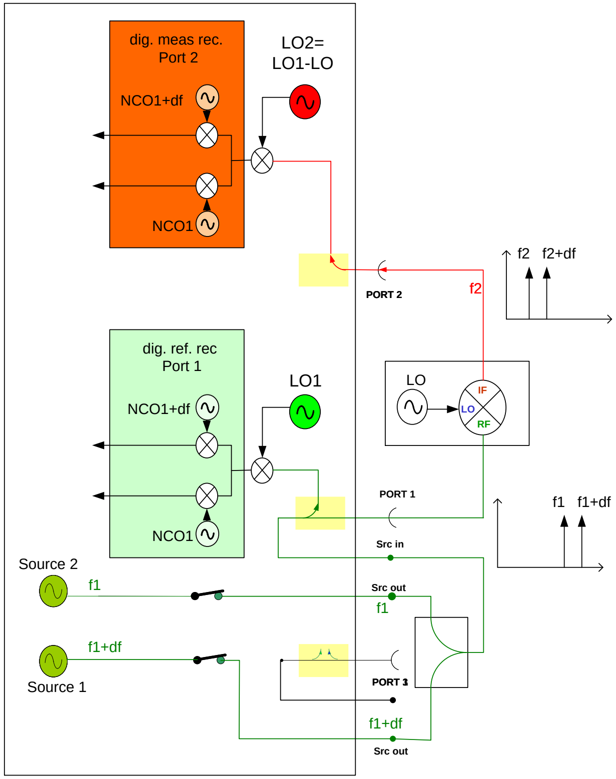
High selective Filters for narrow Frequency Aperture

- Typical VNA IF-filters are designed for fast settling and measurement of single CW signals
- High sidelobes may cause interference for two tones especially with small offset

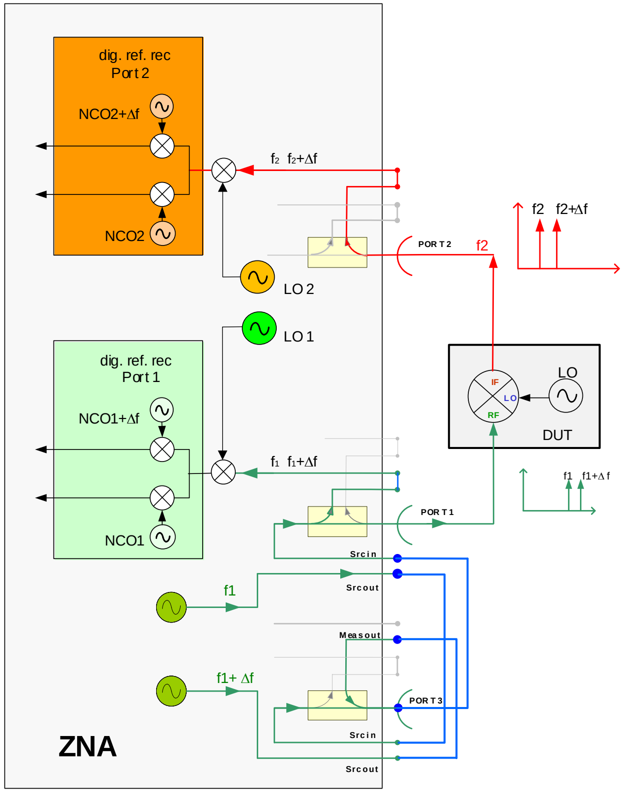
- Solution:
  - High selective digital IF filters
  - High shape factor
  - >70 dB stopband attenuation



The Setup with external Combiner

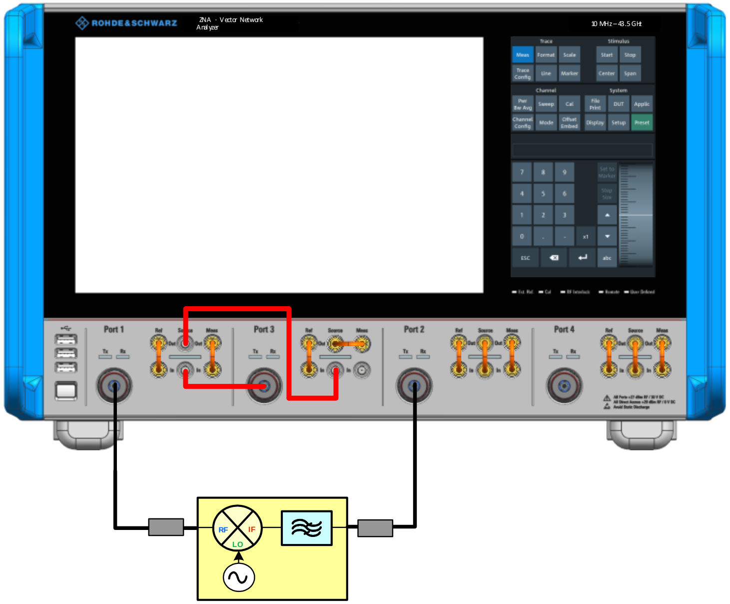


The Setup using the internal Coupler



Setup using internal Coupler

- Fast and easy setup utilizing the coupler of port 3 as internal combiner



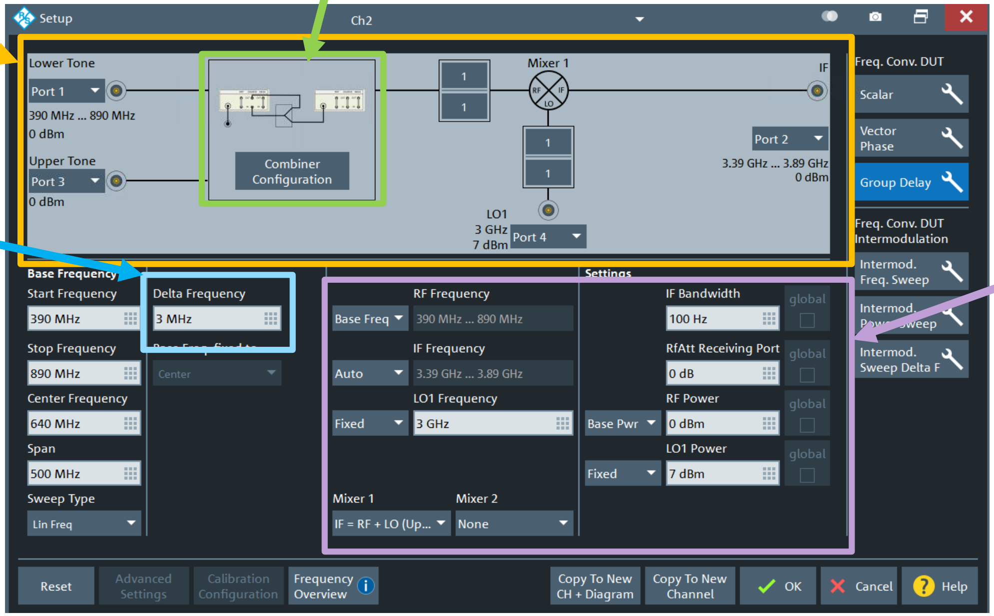
Configuration of Two-Tone Group Delay Measurement

Combination of two tone signals

Connection of the DUT

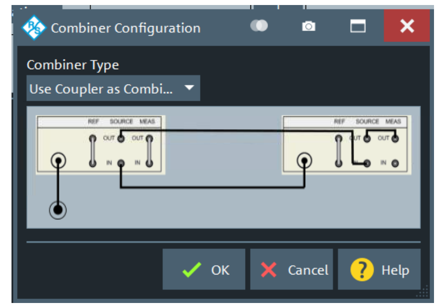
Frequency aperture

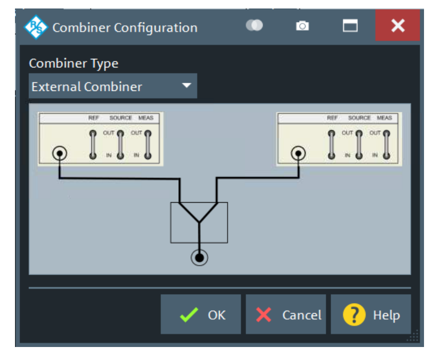
Mixer settings

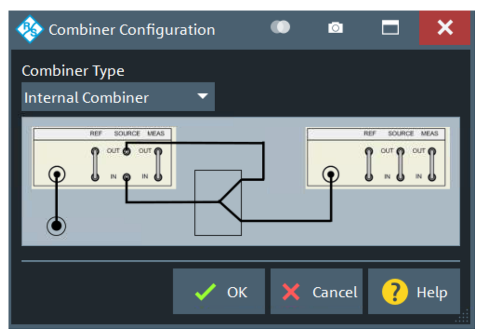


Different Combinations of the two Tone Signals

- Use coupler as combiner
  - ZNA coupler
  - Recommended configuration
- External combiner
  - Two signal with identical power
- “Internal Combiner”





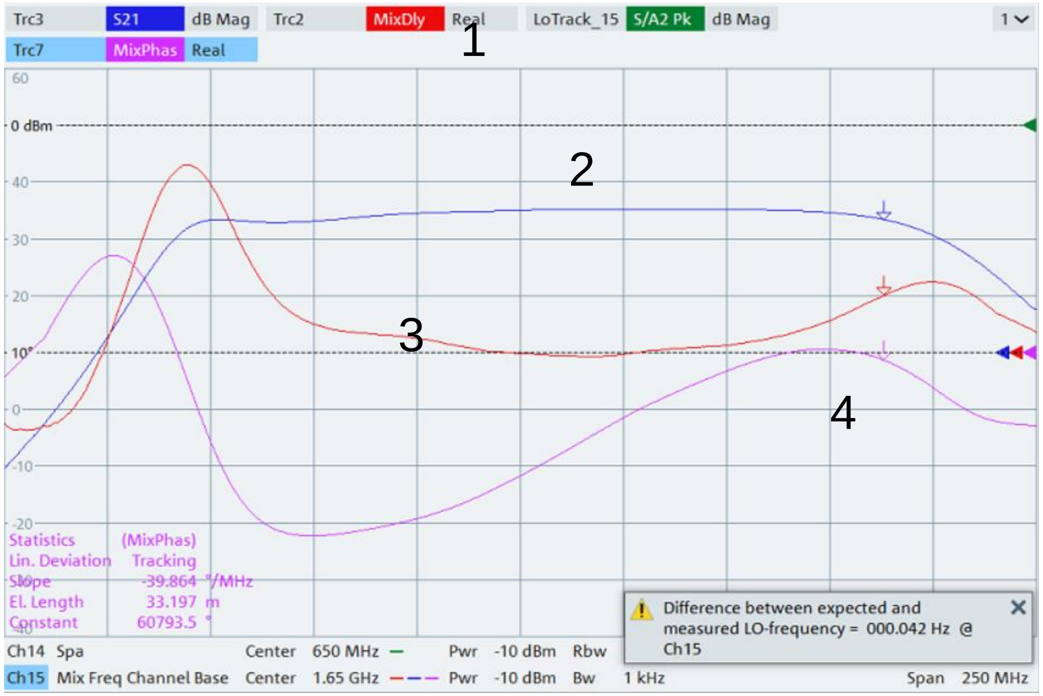


Automatic LO Search Function

- Dut‘s internal LO often unknown
- Requires measurement and readjustment of the mixer settings

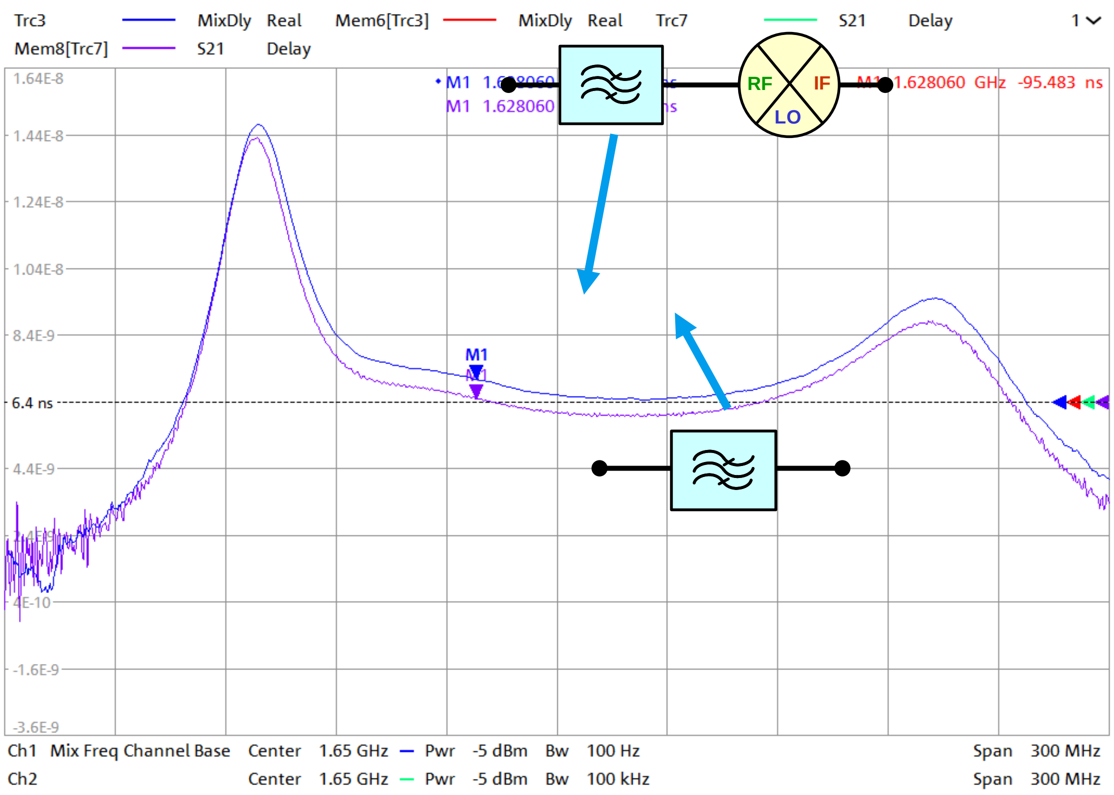
- Solution:
- Automatic search from sweep to sweep
- Re-adjustment of NCO
- No change of frequencies or calibration necessary

Measurement Parameters



1. Conversion loss
2. Group delay
3. Deviation from linear phase
4. Result of LO search

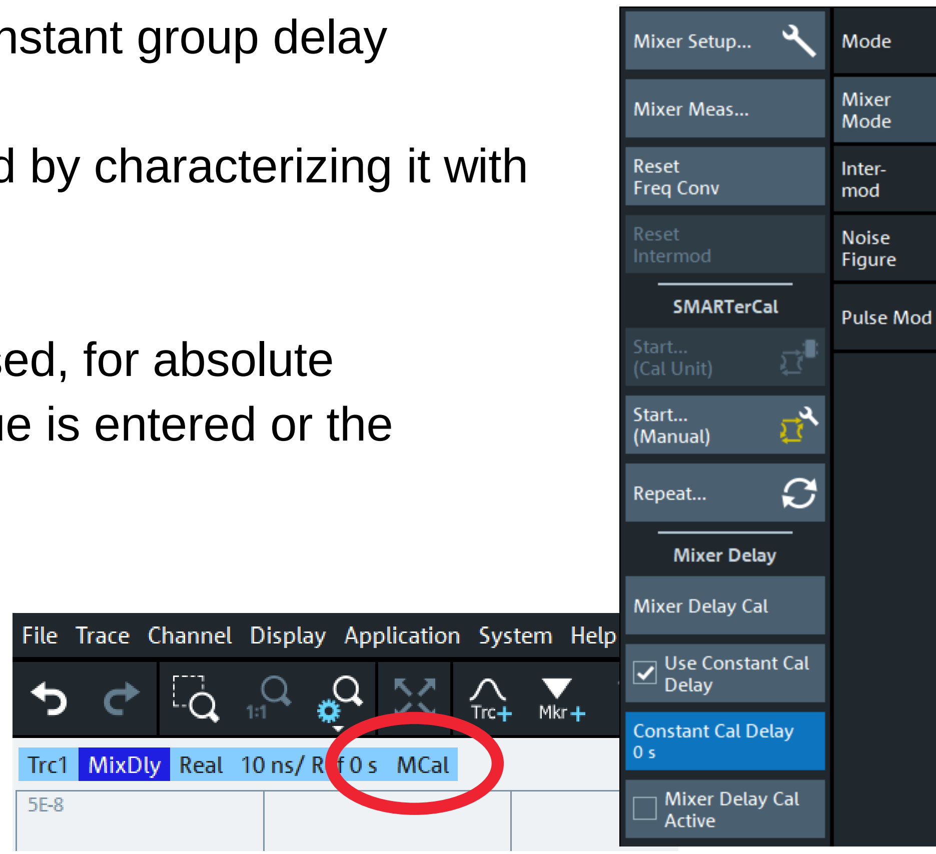
Comparison



- Purple – group delay measurement of the filter without mixer using 2-port calibrated S-parameters
- Blue – group delay measurement of the combination filter + mixer

The Calibration

- Calibration requires a mixer with constant group delay
- Constant group delay can be proved by characterizing it with ZNA-K5
- For relative measurements 0 s is used, for absolute measurements the group delay value is entered or the measured *.csv file
- Calibration is scalar w/o mismatch correction
- => well matched attenuators are recommended

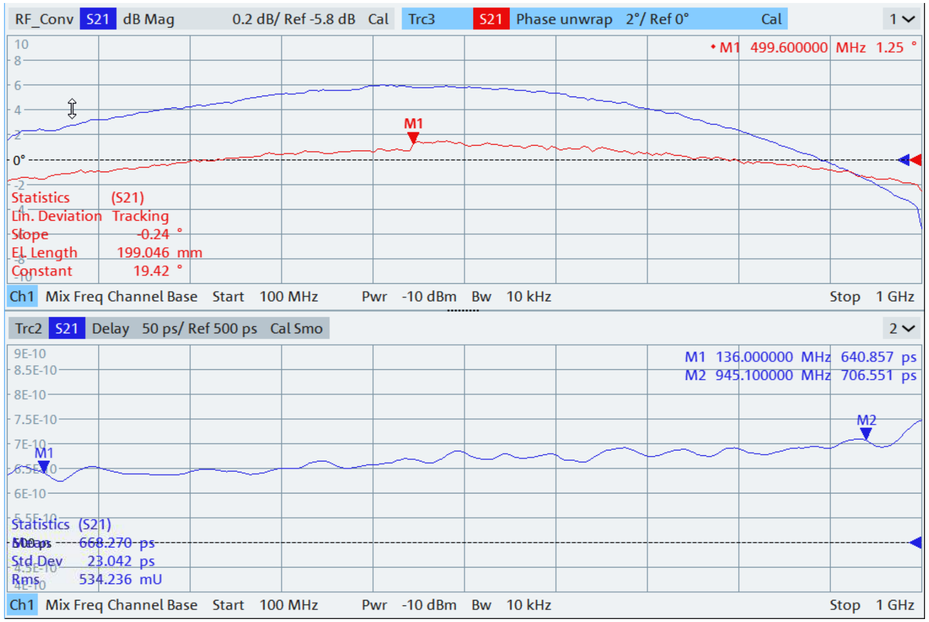


Check whether a Mixer is suitable for Calibration

- There are two ideal mixer characteristics that are relevant for calibration:

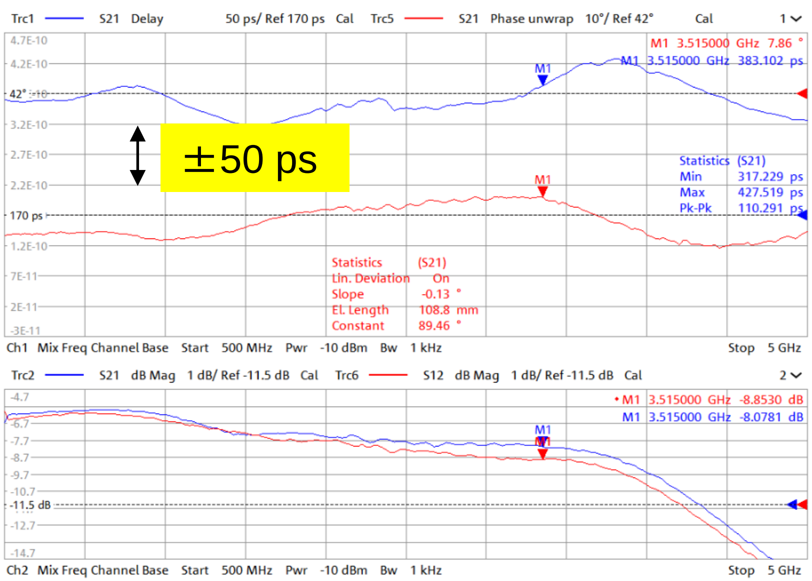
➢ Reciprocity for calibration with ZNA-K5
➢ Constant group delay for group delay calibration with 2-tone method (ZNA-K9)

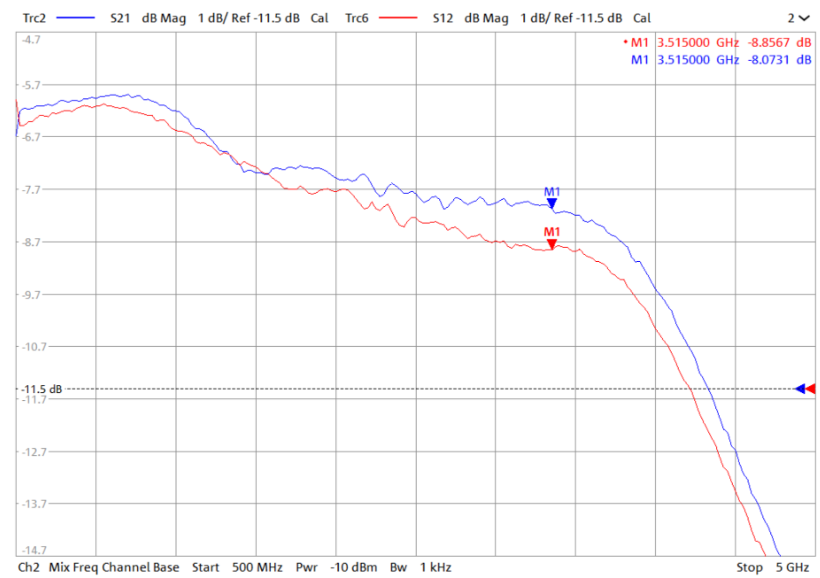
- E.g. Mini-Circuits ZEM 4300: 1 GHz span → 50 ps group delay deviation



Check whether a Mixer is suitable for Calibration

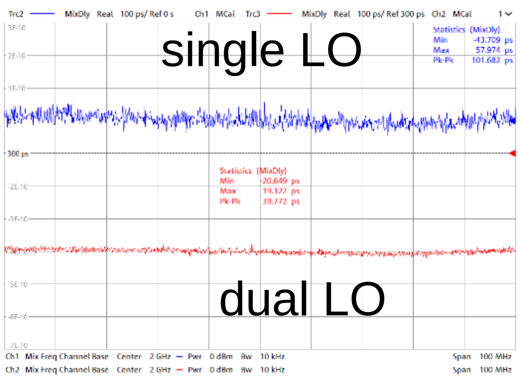
- E.g. Mini-Circuits ZX05 153: 4 GHz Span → 50 ps group delay error
- Magnitude non-reciprocity 1,5 dB → 0,7 dB error

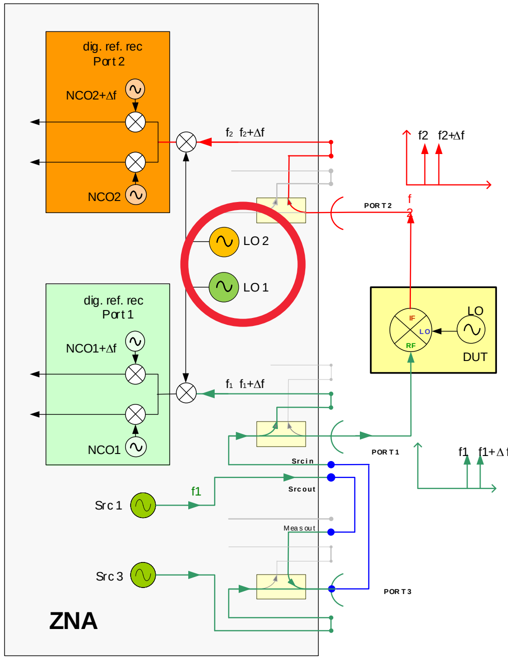




ZNA with double LO (ZNA-K5)

- Use of double internal LO
- Simultaneous measurement of mixer‘s RF and IF (port1 and port2)
  - Compared to sequential measurement of input and output signals
- Doubles sweep speed
- Reduces trace noise
- Comparable to trace noise with vector mixer measurement ZNA-K5

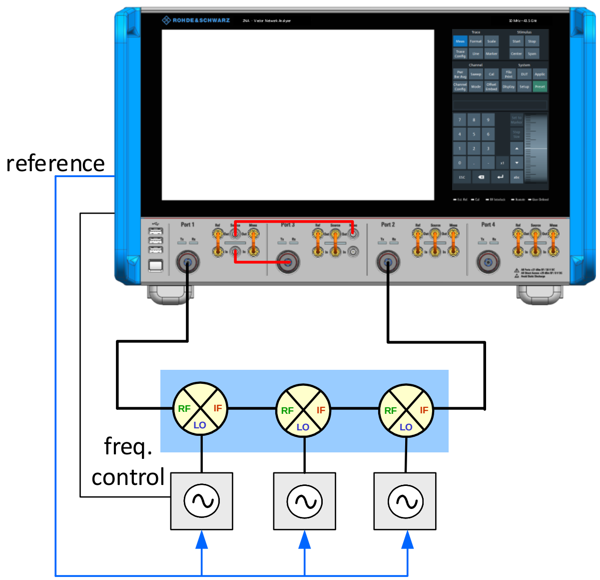


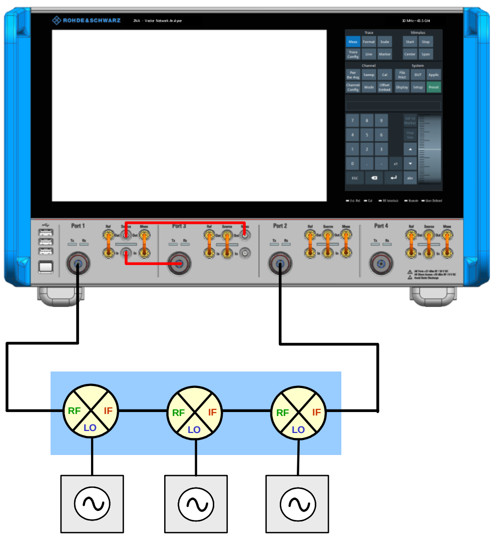


Typical Devices to test with ZNA-K9

- Multi stage converters
- Frequency converters for satellite up- and downlink
- Transponders within a satellite on earth

Measurement on multistage Converters with Two Tone Technique





Multistage converter with swept LO

- LO controlled by ZNA

Multistage Converter with fixed LO‘s

- LO‘s and ZNA‘s ref frequency independent

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